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Blue Stars and Binary Stars in NGC 6397: Case Study of a Collapsed-Core Globular Cluster

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Abstract. The dense central region of NGC 6397 contains three classes of stars whose origins are likely related to stellar interactions: blue stragglers (BSs), cataclysmic variables (CVs), and probable helium white dwarfs (HeWDs). We summarize results to date concerning CVs and HeWD candidates that have been identified in two imaging studies with Hubble Space Telescope (HST), and present one new CV candidate that appears well outside the cluster core. We also present results concerning binaries containing two main sequence stars in the central parts of the cluster. Proper motion information derived from two epochs of HST data is used to remove field stars from the sample. Binaries are then identified on the basis of their positions in the color-magnitude diagram. We set an upper limit of $\sim$3% on the fraction of main sequence stars with primary masses in the range $0.45-0.8\mathcal{M}_\odot$ and mass ratios q $\gtrsim 0.45$. Extrapolating to all mass ratios gives an estimated binary fraction of $\lesssim 5-7\%$. Even in these small numbers, such pairs are likely to be key players in the processes that give rise to the more exotic stellar populations.

1. Introduction

The nearest places in the Universe where stellar collisions should be relatively commonplace are in the central regions of globular clusters with collapsed cores. The nearest such cluster is NGC 6397. At a distance of $\sim$2.7 $\pm$ 0.2 kpc (Reid 1998, Reid & Gizis 1998, Anthony-Twarog & Twarog 2000), its dense central region is both brighter and more spread out on the sky than other high-density cluster cores. NGC 6397 is thus a prime locus in which to study the consequences of stellar interactions.

The inner regions of NGC 6397 are characterized by a power-law surface-brightness profile surrounding a resolved core with a density of $\sim 10^5\mathcal{M}_\odot$ pc^{-3}. Using star counts in HST/WFPC2 images, Sosin (1997) derived a maximum-likelihood core radius of $4.8''$($1''\!.5$–$8''$ at 95% confidence) for stars with masses close to the turnoff mass, consistent with values determined from the ground (e.g., Drukier 1993). Sosin's analysis also revealed a high degree of mass segregation in the central regions, including a mass function that in the inner $\sim 18''$ is inverted, i.e., increases with increasing mass.

The first evidence for unusual stellar populations in NGC 6397 was the discovery of a central concentration of bright blue stragglers (BSs) by Aurière,

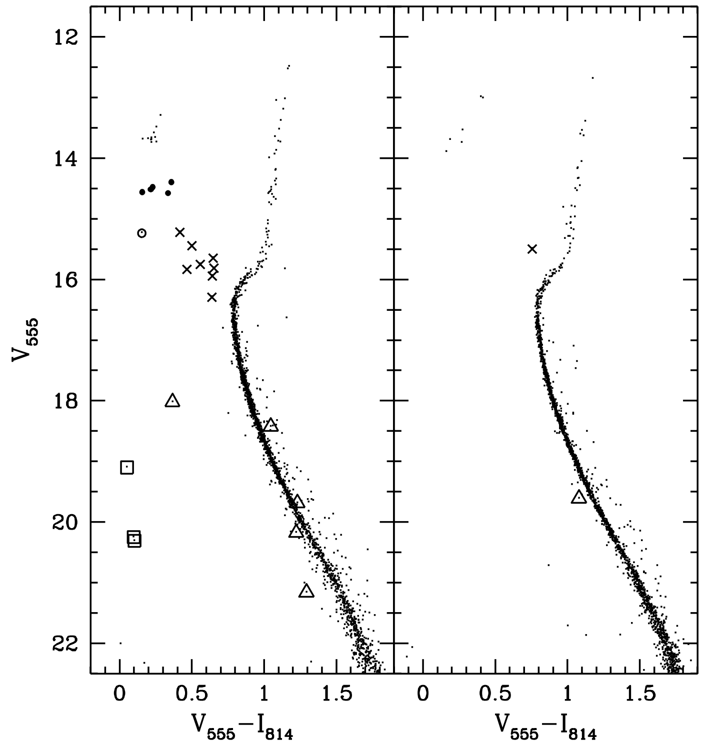

Figure 1. CMDs of stars within 57″ of the cluster center (left) vs. stars outside 57″ (right). Equal numbers of stars appear in these two regions of the WFPC2 field. Solid dots mark the five bright blue stragglers in the cluster core. The bluest of these is the one that lies closest to the cluster center and was found by Saffer *et al.* (this volume) to be most massive. X's mark the fainter blue stragglers, all of which lie at larger radii. Triangles and squares mark cataclysmic variables and probable helium white dwarfs, respectively.

Ortolani, & Lauzeral (1990). Since then, high-resolution imaging with the Wide Field and Planetary Camera 2 (WFPC2) on Hubble Space Telescope (HST) has revealed two more classes of stars whose origins are also likely to be linked to stellar interactions: cataclysmic variables (CVs) and probable helium white dwarfs (HeWDs). The presence of CVs was first signaled by a population of faint X-ray sources detected with ROSAT (Cool *et al.* 1993). Several optical counterparts were subsequently identified via Hα excess, UV excess, and/or variability (De Marchi & Paresce 1994, Cool *et al.* 1995, 1998), and confirmed spectroscopically (Grindlay *et al.* 1995). More recently, a population of blue stars similar in brightness to CVs was found that lacked the photometric variability of CVs (Cool *et al.* 1998). Dubbed "non-flickerers" (NFs), they have been identified as probable helium white dwarfs (HeWDs) (Edmonds *et al.* 1999).

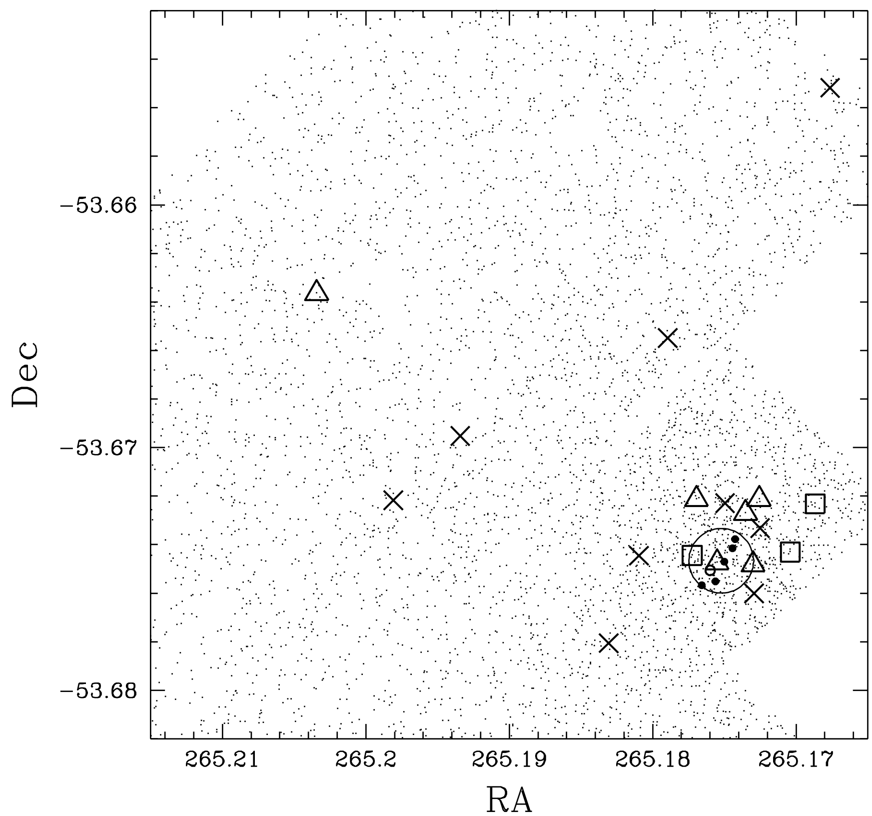

Figure 2. Locations within the WFPC2 field of cataclysmic variables, helium white dwarfs candidates, and blue stragglers. Symbols are as in Fig. 1. The massive blue straggler (Saffer *et al.*, this volume) is the one closest to the center of the cluster (middle one of the five large dots). The center and core radius adopted are those of Sosin (1997): R.A. = $17^{h}40^{m}42\overset{s}{.}06$, Dec. = $-53^{o}\ 40'\ 28\overset{''}{.}8$ (uncertainty $\sim 1.5''$), and $r_c = 4\overset{''}{.}8$ (see text). This center corresponds to (x,y) = (529,378) on HST archive image u33r010kt (PC1 chip). The open circle marks a star that Saffer *et al.* identify as a probable horizontal-branch star; it had previously been identified as a blue straggler (Lauzeral *et al.* 1992).

Here we present results from two epochs of HST/WFPC2 imaging of the central regions of NGC 6397. Several of the results concerning CVs and NFs have appeared elsewhere. We collect those results and present new color-magnitude diagrams (CMDs) showing all the CVs and NFs along with the BSs that appear in the field. We also describe new findings regarding a sixth CV candidate, the first to be found many core radii from the cluster center.

We then discuss initial results of a study of main-sequence binaries in the cluster. This study makes use of the two epochs of WFPC2 data to perform a proper-motion selection to remove field stars from the sample of main-sequence binary candidates. With their large cross sections, such binaries are likely to play a critical role in stellar interactions, affecting the dynamical evolution of the cluster as well as the formation of exotic stellar populations. Understanding the populations of BSs, CVs, and NFs is likely to require an understanding of main-sequence binaries as well.

Fig. 1 shows CMDs for all stars in the two epochs of WFPC2 data brighter than V = 22.5. The BSs, CVs, and NFs are all marked. We have divided the stars into two equally sized groups, one with $r < 57''$(left panel) and one with $r > 57''$ (right panel). It can be seen at a glance that all three populations of stars are strongly concentrated toward the center of the cluster. This central concentration can also be seen in Fig. 2, in which we plot the locations of the BSs, CVs, and NFs within the HST/WFPC2 field.

2. Observations

The central regions of NGC 6397 have been observed twice with the WFPC2 camera on the Hubble Space Telescope (HST). The first data set (hereafter "epoch 1") was taken on 6 – 7 March 1996, and consists primarily of F336W (U_{336}) and F439W (B_{439}) images, with a small number of short exposures in F555W and F814W. The second data set (hereafter "epoch 2") was taken on 3 – 4 April 1999, and consists of F656N (Hα), F555W (V_{555}), F675W (R_{675}), and F814W (I_{814}) images. The epoch 1 observations were taken primarily for a variability study, and so were minimally dithered; the epoch 2 observations were well dithered.

Both epochs of data were centered approximately on the cluster center, with some adjustment made to include an off-center X-ray source in the field. The fields of view of the two epochs are largely, but not completely, overlapping. We stacked co-aligned images following cosmic-ray removal, to produce 2 U_{336}, 2 B_{439}, 1 V_{555}, and 1 I_{814} image for epoch 1, and 13 R_{675} 12 V_{555}, 12 I_{814}, and 15 Hα images for epoch 2. Hereafter we use the term "frame" to refer to these image stacks.

3. Photometric and Astrometric Analysis

Here we briefly outline the photometric and astrometric analysis techniques; details will appear elsewhere (Bolton, Cool, & Anderson 2001). The photometric analysis was carried out using ALLFRAME (Stetson 1994). We constructed empirical point-spread functions for each image, and created the star list by hand to minimize the introduction of artifacts. A total of 7061 stars were identified

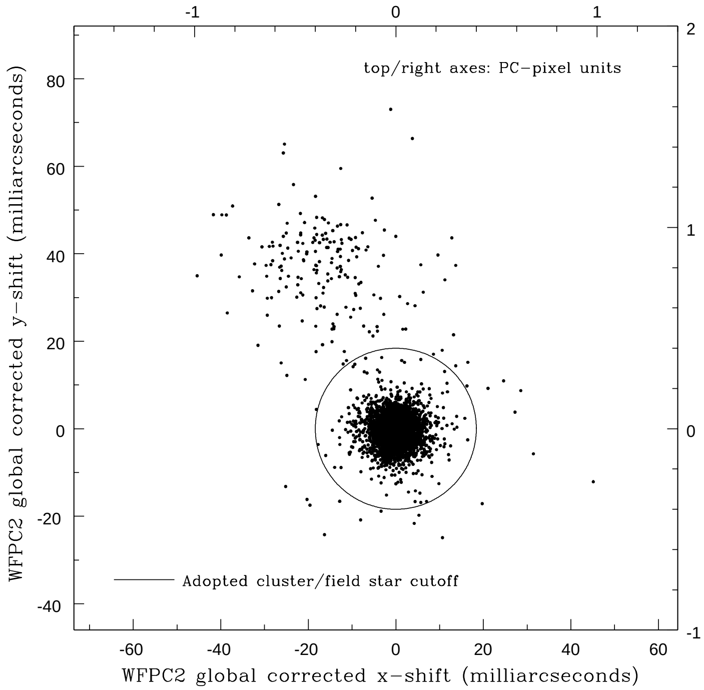

Figure 3. Proper motions of all stars detected in both epochs. Because the transformations are based primarily on cluster stars, cluster members center around (0,0).

and measured (1108, 1969, 1761, and 2223 in the PC1, WF2, WF3, and WF4 chips, respectively).

For the astrometric analysis, we used the technique developed by Anderson & King (2000) (see also Anderson, King & Meylan 1998 and King *et al.* 1998). We first redetermined positions of stars in each frame in both epochs using the code developed by Anderson. These positions were then corrected for geometric distortion using the method prescribed by Holtzman *et al.* (1995). We then predicted a position in the epoch 2 images for each star in the epoch 1 images. This was accomplished for each individual star using its 25 nearest neighbors to determine a local general linear transformation between the two epochs. The chosen transformation was the one that minimized the total square deviation between the transformed and actual positions of the near neighbors. Stars that yielded proper motions > 0.4 PC pixels (relative to the mean of cluster stars) in a first pass were excluded from a second pass at computing the transformations (Bolton, Cool & Anderson 1999).

The differences between the observed and predicted epoch 2 positions are shown in Fig. 3. Cluster members center around (0,0) since the transformations are based primarily on cluster stars (there being many more cluster stars than field stars in the images). A significant population of non-members can be seen offset $\sim$1 PC pixel from the cluster mean, consistent with the offset found in a similar study of stars in another region of the cluster (King *et al.* 1998). The

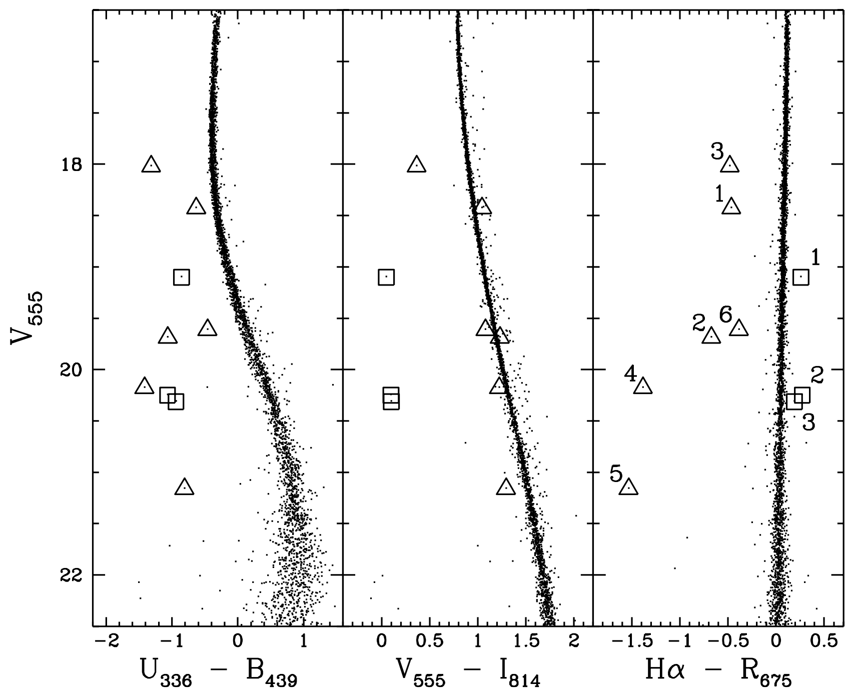

Figure 4. Color-magnitude diagrams for stars in all four WFPC2 chips combined. Cataclysmic variables are marked with triangles; helium white dwarf candidates are marked with squares. Numbering is explained in the text.

separation between the two populations appears quite good. In order to remove the bulk of field stars from the CMDs throughout this paper, we have eliminated stars whose displacement from the cluster mean is more than 0.4 PC1 pixels (see circle in Fig. 3).

4. Cataclysmic Variables

In Fig. 4 we present results of the ALLFRAME analysis for all four chips combined. Three CMDs are shown side by side, with V_{555} on the vertical axis in all cases. The colors in the left panel ($U_{336}-B_{439}$) come from the epoch 1 data, while the colors in the center and right panels ($V_{555}-I_{814}$ and $H\alpha-R_{675}$, respectively) come from the epoch 2 data. Only stars that meet the criterion for membership described above are plotted. Cataclysmic variables (CVs) are marked with triangles. We confine our discussion here to the brighter stars; results from a search for CV candidates among the fainter stars will appear elsewhere (Grindlay *et al.* 2001).

CVs $1-3$ are those first identified on the basis of $H\alpha$ excess in Cycle 1 WFPC1 R_{675} and $H\alpha$ images (Cool *et al.* 1995). CV 4 was identified via its variability in epoch 1 data, which also showed CVs $1-3$ to be variables (Cool *et al.* 1998). CV 5 was identified in a search for an optical counterpart to an X-ray

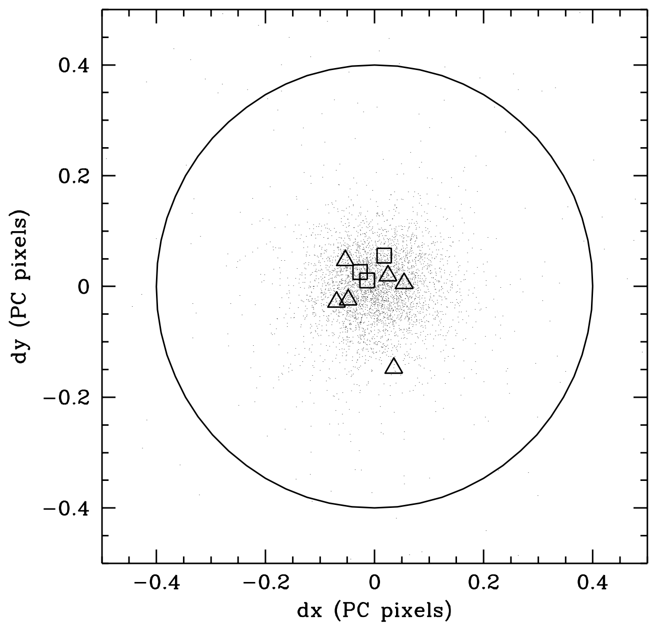

Figure 5. Close-up of a portion of Fig. 3, with CVs and NFs marked (symbols are as in Fig. 3). All nine stars easily meet the criterion for proper-motion membership (see text).

source identified by Metchev (1999) in a deep (75 ksec) ROSAT HRI exposure (see also Verbunt & Johnston 2000). It appeared as a U-bright object in the epoch 1 data, and could also just barely be seen in the wings of a bright star in the Cycle 1 WFPC1 Hα images (Grindlay 1999). These five stars are all within $\sim 11''$ of the cluster center (see Fig. 2), in a region of multiple overlapping ROSAT/HRI X-ray sources. HST/FOS spectra that have been obtained of CVs $1-4$ all show Balmer emission lines; CVs $1-3$ also show He II in emission, suggesting that they are weakly magnetic, i.e., DQ Her-type, systems (Grindlay *et al.* 1995, Edmonds *et al.* 1999).

CV 6 is new. With magnitudes and colors similar to those of other CVs in the cluster, and with a proper motion consistent with membership (see Fig. 5), it is a strong candidate. It also appears to have a faint counterpart in the deep ROSAT HRI exposure whose X-ray flux is consistent with its being a CV (Metchev 1999; Verbunt & Johnston 2000). Of particular interest is its position in the cluster, roughly $72''$, or about 15 core radii, from the center (see Fig. 2). (Note that it was outside the smaller field of view of the WFPC1 Hα study.) It is the only one of six CVs in NGC 6397 that lies more than about three core radii from the cluster center.

5. Helium White Dwarf Candidates

The third class of exotic stars in the central regions of NGC 6397 was discovered in the epoch 1 data. Three faint blue stars were found that distinguished themselves from CVs in two ways. First, they lacked the photometric variability

seen in the CVs. Second, they had the broad-band colors of B stars rather than the UV excesses typical of CVs. These three stars are marked with squares in Figs. 1, 2, 4 and 5, and numbered as in Cool *et al.* (1998). The difference in the broad-band colors of NFs vs. CVs can be seen by comparing the left and center panels in Fig. 4. In $U_{336}-B_{439}$ (left panel) they appear very similar, whereas in $V_{555}-I_{814}$ (middle panel) the CVs lie close to the main sequence while the NFs remain well to the blue side of the main sequence.

We note that two of these "non-flickering" stars had been seen in previous studies, and, being blue, were taken to be possible CVs. NFs 2 and 3 correspond to stars 7 and 6, respectively, of Cool *et al.* (1995), while NF 3 is star 4 of De Marchi & Paresce (1994), who identified it in HST Faint Object Camera data.

The magnitudes and colors of the NFs are consistent with those of low-mass white dwarfs (Cool *et al.* 1998). Low-mass (helium) WDs have larger radii than the more common $\sim 0.5 - 0.6\ \mathcal{M}_\odot$ carbon-oxygen (CO) WDs. This places them to the red side of the sequence of $\lesssim 100$ CO WDs identified in the epoch 1 data (Cool, Sosin & King 1997), and the smaller number measured in HST images of an off-center field in the cluster (Cool, Piotto & King 1996).

Stronger evidence that at least one of the NFs is a helium white dwarf was presented by Edmonds et al. (1999), who obtained a spectrum of NF 2 with the HST Faint Object Spectrograph. They found that it had a broad Hβ absorption line, consistent with a high gravity of log g $\simeq 6.3$. Further evidence that the other two NFs are likely to be similar in nature to NF 2 can be seen in the right panel of Fig. 4. All three appear at similar offsets to the right of the vertical main sequence in this diagram, signifying that the equivalent widths of their Hα absorption lines are comparable. More detailed analyses of these stars are presented by Taylor *et al.* (2001), who also identify additional fainter candidate members of the class.

6. Main-Sequence Binary Stars

Main-sequence binaries that are compact enough to survive in a globular cluster will be unresolved with HST at the distance of even the nearest globulars. But they can in principle be distinguished photometrically, as the combined light from the two component stars will be brighter and/or redder than that from a single main-sequence star. An advantage of this technique, which has been explored in detail by Romani & Weinberg (1991), is that it is sensitive to binaries irrespective of their orbital period or inclination. Thus it is complementary to techniques that rely on photometric variability (i.e., eclipses) or radial velocity variations (see Hut *et al.* 1992 for a review).

In Fig. 6 we show the CMD resulting from our ALLFRAME analysis of the WFPC2 V_{555} and I_{814} images. Only proper-motion members are plotted. To select candidate binaries, we began by fitting a ridge line to the main sequence. This was accomplished by determining the mean $V_{555}-I_{814}$ color in 0.25 magnitude bins along the sequence, with outliers excluded, and iterating until the mean converged for each bin. Within each iteration, the boundary between main-sequence stars and "outliers" was selected so that over the whole sequence fewer than 0.5 stars would be expected to lie beyond the boundary if the errors in color were Gaussian. The final boundary determined in this way appears as

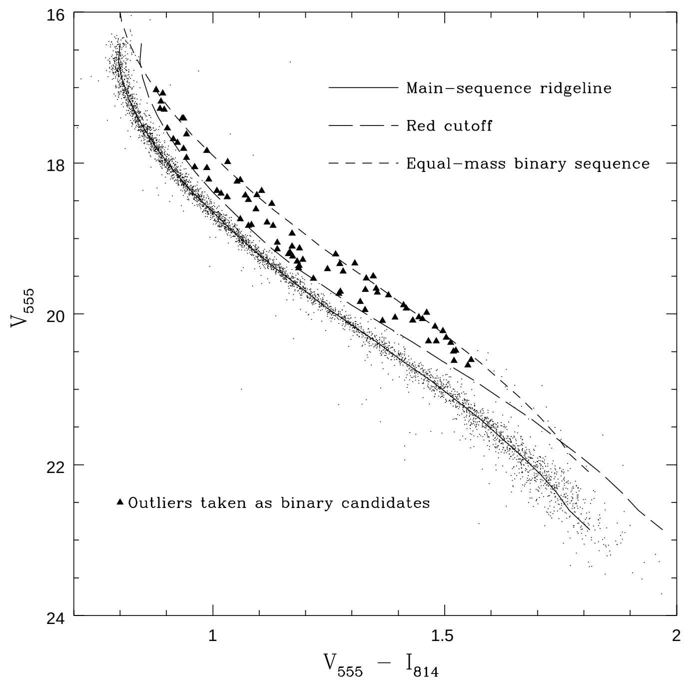

Figure 6. Candidate main-sequence binary stars in the WFPC2 field.

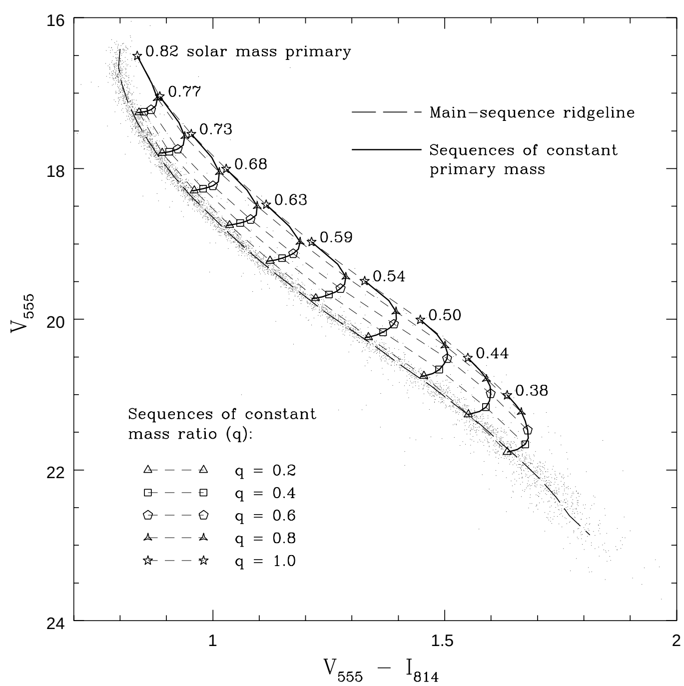

Figure 7. Model binary sequences constructed using our empirical main-sequence ridge line and the model mass–luminosity relations of Alexander *et al.* (1997). A distance modulus of $(M-m)_V = 12.6$ and a reddening of $E(V-I) = 0.19$ were adopted for this study.

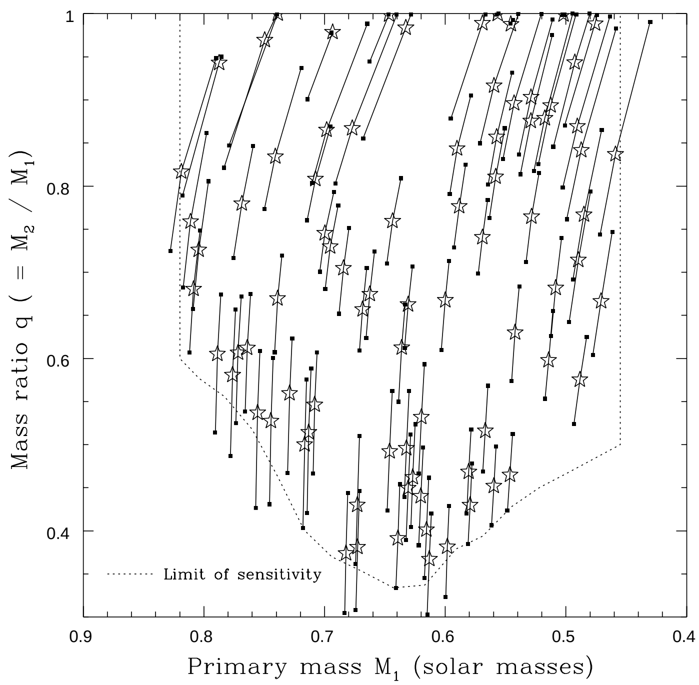

Figure 8. Primary mass vs. mass ratio for candidates shown in Fig. 7. Photometric uncertainties translate into highly eccentric error ellipses, the major axes of which are plotted. Uncertainties in the mass ratio are typically at the level of $\lesssim$ 0.1 and in some cases are as low as $\sim$0.05.

the "red cutoff" in Fig. 6. We identify stars redward of this boundary as binary candidates. Some portion of them will be chance superpositions of unrelated stars in the cluster, an issue to which we will return below.

A total of 81 stars appear in the binary region of Fig. 6. This represents $\sim$3% of the $\sim$2500 stars in the magnitude range V_{555} $\sim$$17-21$. This figure is not representative of the entire population of main-sequence binaries, however. Some will be missed, namely those for which the secondary star contributes too little light to the system to shift its color appreciably off the main-sequence ridge line.

The limitation imposed by mass ratio is illustrated in Fig. 7. As increasingly massive secondary stars are combined with a primary star, the binary's light first becomes redder, then brighter, then turns back to the blue until, for equal mass systems, the combined light is the same color but twice as bright as that of the primary star. In order to identify specific stars as candidate binaries (as opposed to doing a statistical analysis–see, e.g., Romani & Weinberg (1991)), sufficiently large mass ratios are required in order to pull the star far enough away from the ridge line of the main sequence that it can be distinguished from a single star.

We have determined best values for the primary mass and mass ratio of each of the candidate binaries by comparing their V_{555} and I_{814} magnitudes to those of a grid of model binaries like those shown in Fig. 7. The results are shown in

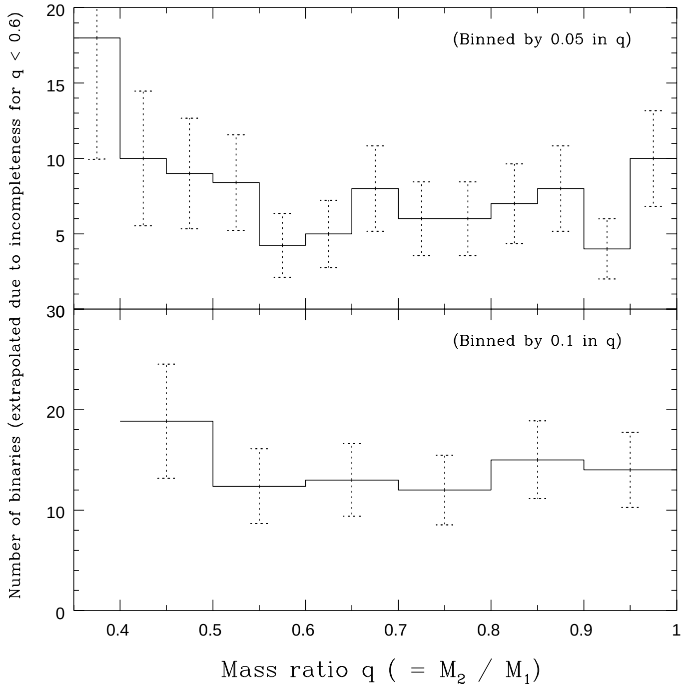

Figure 9. Histogram of mass ratios of binary candidates. Error bars are based on root-N statistics.

Fig. 8. Here it can be seen that we are sensitive to binaries with primary masses in the range $\mathcal{M}_1 \sim 0.8 - 0.45 \mathcal{M}_\odot$ and mass ratios as low as $\sim$0.4. A more typical limiting mass ratio is q $\gtrsim$ 0.45. This sensitivity range is set by a combination of the slope of the main sequence and the photometric error as a function of magnitude. Based on these sensitivity limits, we place an upper limit of 3% on the binary fraction among main sequence stars with primary mass in the range $0.45 - 0.8\ \mathcal{M}_\odot$ and mass ratios q $\gtrsim$ 0.45.

This figure represents an upper limit because a portion of the candidates we identify will be chance superpositions of two physically unrelated stars in the cluster. The WFPC2 images are not tremendously crowded, with $\sim$1000 $-$ 2000 stars per 800$\times$800-pixel chip, owing in part to the relative proximity of NGC 6397. But with the binary fraction being so low, chance coincidences are a potentially important factor. We estimate that as many as $\frac{1}{3}$ to $\frac{2}{3}$ of the candidates could be chance superpositions. Non-Gaussian errors could also push more stars into the part of the CMD associated with binaries. Additional work is underway to try to constrain the numbers of chance coincidences more precisely. If a significant portion of the candidates are superpositions, the binary fraction in the cluster will be correspondingly reduced. It could also impact our preliminary conclusions about the distribution of binaries as a function of primary mass and mass ratio. Nevertheless, the 3% figure we have determined represents a firm upper limit on the main-sequence binary fraction for q $\gtrsim$ 0.45.

We can take this one step further to obtain an estimate of the total main-sequence binary fraction by extrapolating to lower mass ratios. Judging from Fig. 8, binaries are fairly uniformly distributed in $\mathcal{M}_1$ and q. Binning by mass ratio produces the results shown in Fig. 9, which also suggest that the distribution of binaries as a function of q is quite flat. Extrapolating this flat distribution to lower mass ratios, we estimate the total main-sequence binary fraction in the central regions of NGC 6397 to be $\lesssim 5-7\%$.

7. Discussion

Stars in the middle of dense clusters must collide. Newton's laws and the laws of probability require it. But the outcomes of the collisions, and especially of the more numerous near misses, are less certain. With HST it is possible to observe the products of these interactions directly. In NGC 6397, every type of star seems to be in on the action. Main sequence stars are combining to form blue stragglers; white dwarfs are coupling with main-sequence stars to form cataclysmic variables; giants are being stripped of their envelopes to reveal their helium cores.

The details of the particular processes that are generating this stellar menagerie will take time to sort out. Multiple pathways exist by which each of these classes of stars may form, and the presence of binaries, even in the small numbers found here, multiplies the possibilities. Formation rates, lifetimes, and destruction/ejection rates all need to be factored in to make sense of the variety and distributions of objects being found. The growing sophistication of simulations of clusters and stellar interactions, coupled with improved constraints on the numbers and distributions of both ordinary and extraordinary stars in clusters, holds out the promise of significant progress in the near future. New dynamical modeling of NGC 6397, making full use of the new information HST has provided, would clearly be valuable. Here we draw attention to a few points of particular interest that may bear further investigation.

(1) Why are there so few main-sequence binaries in NGC 6397?

The limit that we place on the main-sequence binary fraction in NGC 6397 is one of the lowest reported for a globular cluster. Most values, obtained using a variety of different techniques, range upward of 10% (see Hut *et al.* 1992 for a review). Particularly notable is the much higher fraction (15%–38%) measured by Rubenstein & Bailyn (1997) in the center of NGC 6752, another nearby, core-collapsed cluster with otherwise similar properties.

Perhaps NGC 6397 is farther along in the process of burning up its original store of binaries than NGC 6752. The short relaxation time in NGC 6397 is likely to facilitate the rapid feeding of binaries into the core where they will quickly be modified through interactions with other stars (McMillan & Hut 1994, and references therein), perhaps even to form some of the blue stragglers now seen in the core. But the present dynamical properties of NGC 6752 are not so different from those of NGC 6397 as to make this a particularly satisfying hypothesis. Whether their past histories (e.g., the timing of core collapse) might be sufficiently different one can only speculate about, and the possibility remains that the two clusters were simply born with significantly different binary populations.

Still, it appears likely that the main-sequence binaries we now observe in NGC 6397 are a vestige of the original population. Large interaction cross sections coupled with the short relaxation times in NGC 6397 ($\sim 10^5$ yr in the center; $\sim 2 \times 10^8$ yr at the half-mass radius of $2\rlap{.}'8$—Djorgovski 1993) make binaries extremely vulnerable to destruction through a variety of direct and indirect processes. Even if the binaries we are now seeing were formed when the cluster was born, it appears that few will been left unscathed. Judging from the calculations of Davies (1995), the rates of binary hardening and exchange interactions should be sufficiently high in this cluster that most systems will have significantly reduced periods, and some fraction of their present components will not be original. Thus it remains to be seen, for example, whether the distribution of mass ratios that we derive has more to say about the cluster's primordial population of binaries or about the nature of exchange interactions. Either way, the fraction of these binaries, while small, is large enough to contribute significantly to the production of CVs, NFs, and/or BSs (Davies 1995).

(2) What accounts for the distribution of BSs, CVs, and NFs?

Saffer *et al.* (this volume) have measured masses for the five bright blue stragglers in the core of NGC 6397 (see Fig. 2). Four have masses of about twice the turnoff mass; the fifth is of order three times the turnoff mass. Interestingly, the latter is the blue straggler closest to the cluster center—exactly where one might expect the most massive objects to reside (see Fig. 2). Its position is consistent with being at the cluster center, according to the star count analysis of Sosin (1997) as well as the ground-based analysis of Aurière *et al.* (1990).

The distribution of the remaining bright BSs is more puzzling. Why are they so much more concentrated toward the center than the CVs, which ought to have comparable (though somewhat lower) masses? The NFs present a puzzle of their own. Within the limits of small-number statistics, their distribution appears similar to that of the CVs. Yet if they are He WDs, their masses are much too low ($\sim 0.25\mathcal{M}_\odot$) to account for this similarity. A natural solution is that they have binary companions. Companions are needed in any case to explain the formation of a He WD, whether through Roche-lobe overflow or via common-envelope evolution following the collision of a red giant with another star. Sufficiently massive main-sequence companions are ruled out (Cool *et al.* 1998), but neutron stars, or possibly massive white dwarfs, are viable. Edmonds *et al.* (1999) find preliminary evidence for binarity in the radial velocity of the one NF for which a spectrum has been obtained; additional studies are clearly needed.

This still leaves open the question of why the bright BSs are much more concentrated than either the CVs or NFs. One factor that may distinguish the BSs from the CVs and NFs is binarity. The CVs are certainly binaries; the NFs make little sense as He WDs unless they too are binaries. The bright BSs show no evidence for photometric variability that would suggest binarity (in contrast to some of the fainter BSs in the cluster—Cool *et al.* 2001). Perhaps the recoil that binaries experience in interactions with other stars keeps them more spread out, on average, than single stars of comparable mass.

A further puzzle is that all three populations (BSs, CVs, and NFs) appear much more centrally concentrated than the population of $1.4\mathcal{M}_\odot$ neutron stars that Dull (1996) included in his Fokker-Planck model of NGC 6397. Yet

their masses should all be roughly comparable. This suggests that not all of these objects have come into equilibrium with the other stars in the cluster, despite having lifetimes well in excess of the relevant 2-body relaxation times. Meanwhile, Sosin's (1997) analysis of the epoch 1 HST data suggests that the main-sequence stars *are* in energy equipartition with one another within the cusp (radius $\sim 100''$). It will be interesting to see whether this apparent discrepancy between the behavior of main-sequence stars and probable interaction products is borne out in future dynamical model that take account of the HST results.

(3) Why is CV 6 out at $\sim$15 core radii?

Numerical simulations have shown that close binary stars in dense cluster cores are vulnerable to interactions with passing stars that can eject the binaries from the cluster. If its recoil velocity is insufficient to escape from the cluster, the binary may spend considerable time at large radii before sinking back to the central region of the cluster. If this has happened to CV 6, it appears that it would likely have been a relatively recent occurrence. The central relaxation time in NGC 6397 is exceedingly short; even at the half-mass radius ($\sim 170''$) it is only $\sim 2\times 10^8$ yr. Unless its radial distance from the center is much greater than its $72''$ projected distance, CV 6 shouldn't take long to migrate back into the center.

In view of the possibility that CV 6 has been ejected from the center in the relatively recent past, it appears somewhat tantalizing at first glance that in the proper motion diagram of Fig. 5, CV 6 is the triangle offset from the rest of the CVs and NFs. However, CV 6 is the only CV that lands on a WF chip rather than on the PC1 chip. The larger WF pixels will result in a correspondingly larger uncertainty in the measurement of its proper motion. Moreover, the direction of motion implied by the proper motion (assuming for the moment that the offset from (0,0) is significant) is closer to being tangential than radial. We conclude that it is most likely that the offset of the proper motion of CV 6 from (0,0) is little more than measurement error. Further refinements by Anderson and King of the astrometric techniques they have developed for WFPC2 may permit direct measurements of the internal motions of cluster stars in the near future (see, e.g., Anderson *et al.* 1998). Such measurements of this and the other CVs, NFs, and BSs in NGC 6397 would be of particular interest.

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